NGU
Norges geologiske undersøkelse
Geological Survey of Norway

GEOLOGI FOR SAMFUNNET
GEOLOGY FOR SOCIETY

NGU Report 2012.075

Magnetic and radiometric helicopter measurements in Nissedal area, Telemark

Norges geologiske undersøkelse
Postboks 6315 Sluppen
7491 TRONDHEIM
Tlf. 73 90 40 00
Telefaks 73 92 16 20

RAPPORT

Report nr.: 2012.075	ISSN 0800-3416	Grading: Open

Title:
Magnetic and radiometric helicopter measurements in Nissedal area, Telemark.

Authors: Frode Ofstad and Vikas C. Baranwal	Client: NGU – Regiongeologen i Buskerud, Telemark og Vestfold
County: Telemark	Municipality: Nissedal
Map-sheet name: (M=1:250.000) Skien	Map-sheet no and name: (M=1:50.000) 1513-2 Fyresvatnet and 1613-3 Nissedal
Area name and coordinates: Nissedal UTM 32V 470000 N – 6560000 E	Number of pages: 18 Price: kr 100,- Map enclosures:

Fieldwork carried out:	Date of report:	Project no:	Person responsible:
20.07.2011	18.02.2015	327601	Jan S. Rønning

Summary:

NGU conducted an airborne magnetic and radiometric survey in the Nissedal area in July 2011 on behalf of the Region Geologist in Buskerud, Telemark and Vestfold; Sven Dahlgren.

This report describes and documents the acquisition, processing and visualization of recorded datasets. The geophysical survey results reported herein covers 525 line km, an area of 105 km^2.

A Scintrex CS-2 magnetometer in a towed bird and a 1024 channels RSX-5 spectrometer installed under the helicopter belly was used for data acquisition.

The survey was flown with 200 m line spacing, line direction 90^o (E to W) and average speed of about 115 km/h. The average terrain clearance was 47 m for the bird and 80 m for the spectrometer.

Collected data were processed at NGU using Geosoft Oasis Montaj software. Raw total magnetic field data were corrected for diurnal variation and levelled using standard micro-levelling algorithm.

Radiometric data were processed using standard procedures recommended by International Atomic Energy Association.

Data were gridded with the cell size of 50 x 50 m and presented as a shaded relief maps at the scale of 1:50.000.

Keywords:	Geophysics	Helicopter
	Magnetic	Radiometric
		Technical report

CONTENTS

FIGURES

TABLES

1. INTRODUCTION

NGU, in cooperation with the Region Geologist in Telemark, Buskerud og Vestfold; Sven Dahlgren, performed airborne geophysical measurements in Nissedal area, across Lake Nisser in Telemark County. The survey was done on July 20th 2011, using NGUs helicopter borne geophysical instruments. The results reported herein amount to 525 line km, or 105 km^2 over the survey area, mainly in Nissedal municipality, about 60 km west of Skien, as shown in Figure 1.

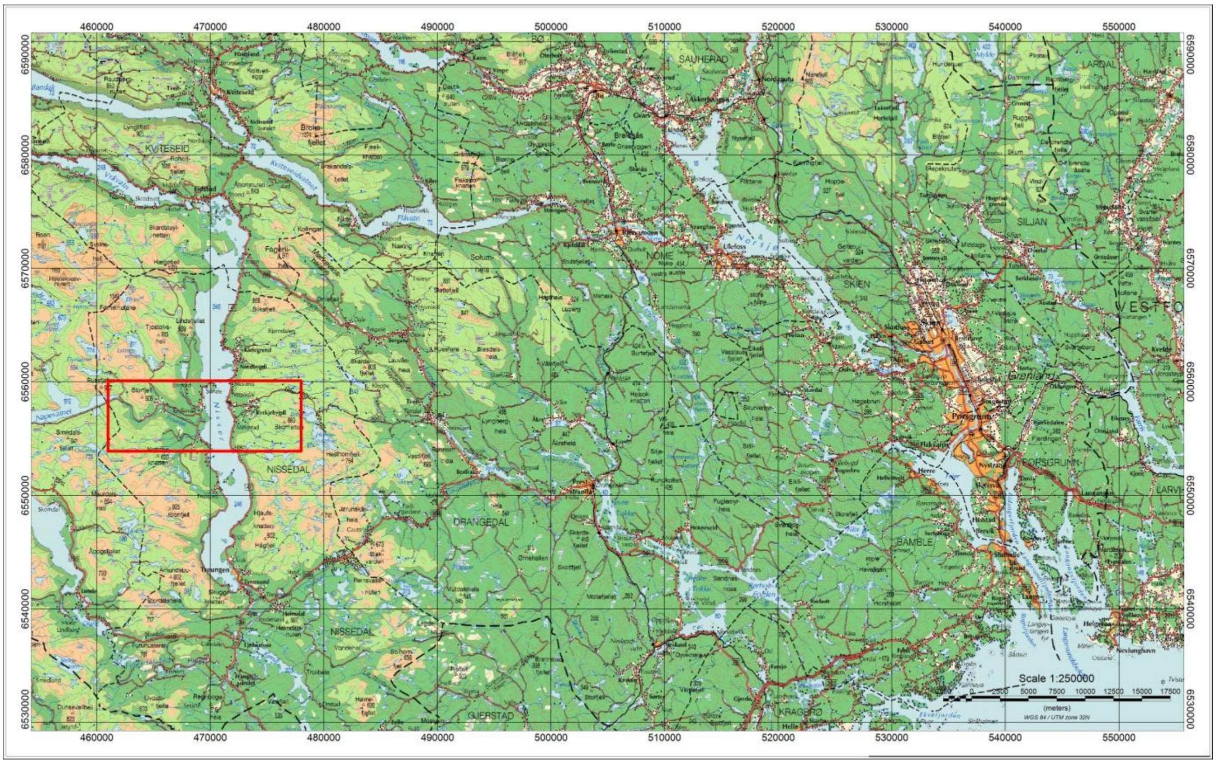

Figure 1: Overview of Nissedal survey area

The objective of the airborne geophysical survey was to obtain a dense high-resolution aero-magnetic and radiometric data set over the survey area. This data set is required for the enhancement of a general understanding of the regional geology of the area. In this regard, the data can also be used to map contacts and structural features within the area. It also improves defining the potential of known zones of mineralization, their geological settings, and identifying new areas of interest.

The survey incorporated the use of a high-sensitivity Cesium magnetometer, gamma-ray spectrometer and radar altimeter. A GPS navigation computer system with flight path indicators ensured accurate positioning of the geophysical data with respect to the World Geodetic System 1984 geodetic datum (WGS-84).

2. SURVEY SPECIFICATIONS

2.1 Airborne Survey Parameters

NGU used a helicopter survey system designed to obtain detailed airborne geophysical data. The magnetic sensor system was supplemented by one 1024 channel gamma-ray spectrometer with 16 liters downward and 4 liters upward crystal volume, which was used to map ground concentrations of Uranium, Thorium and Potassium.

An Eurocopter AS350-B2 from helicopter company HeliScan AS was used during the survey. Line spacing 200 m apart, orientation 90° azimuth in UTM zone 32V. The detailed survey area with flight lines is shown in Figure 2.

Figure 2: Nissedal survey area with flight lines

The magnetic sensor was housed in a Hummingbird^{TM} EM-bird, which was flown at a constant altitude above the topographic surface. The Radiation Solutions RSX-5 gamma-ray spectrometer was installed under the belly of the helicopter, registering natural gamma ray radiation simultaneously with the acquisition of magnetic data.

Large water bodies, rugged terrain and abrupt changes in topography affected the pilot's ability to 'drape' the terrain; therefore there are positive and negative variations in sensor height with respect to the standard height, which is defined as 60 m plus a height of obstacles (trees, power lines). The average survey height for the magnetometer was 47 m, and 80 m for the spectrometer.

The ground speed of the aircraft varied from 50 – 150 km/h depending on topography, wind direction and its magnitude. On average the ground speed during the whole survey was calculated to 115 km/h. Magnetic data were recorded at 0.2 second intervals resulting in approximately 6.4 meters point spacing. Spectrometry data was recorded every 1 second giving an average point spacing of 32 meters.

The above parameters were designed to allow for sufficient details in the data to detect subtle anomalies that may represent mineralization and/or rocks of different lithological and petro-physical composition. The relatively high average survey speed was necessary to complete the whole survey in two flights.

A base magnetometer to monitor diurnal variations in the magnetic field was located at Gautefall, about 10 km south-east of the survey area, at UTM 32V: 6546850 N, 484270 E. The Scintrex Envi-Mag base station magnetometer data were recorded once every 3 seconds.
Navigation system uses GPS/GLONASS satellite tracking systems to provide real-time WGS-84 coordinate locations for every second. The accuracy achieved with no differential corrections is reported to be less than ± 5 m in the horizontal directions. The GPS receiver antenna was mounted externally to the tail of the helicopter.

For quality control, the magnetic, radiometric, altitude and navigation data were monitored in the operator's display during flight while they were recorded in ASCII data streams to the acquisition PC hard disk drive.

2.2 Airborne Survey Instrumentation

Table 1: Instrument Specifications

Instrument	Producer / Model	Accuracy / Sensitivity	Sampling freq / interval
Magnetometer	Scintrex Cs-2	0.002 nT	5 Hz
Base magnetometer	Scintrex Envi-Mag	0.1 nT	3 s
Gamma spectrometer	Radiation Solutions RSX-5	1024 ch's, 16 liters down, 4 liters up	1 Hz
Radar altimeter	Bendix/King KRA 405B	± 3 % 0 – 500 ft ± 5 % 500-2500 ft	1 Hz
Pressure/temperature	Honeywell PPT	± 0.03 % FS	1 Hz
Navigation	Topcon GPS-receiver	± 5 meter	1 Hz
Acquisition system	NGU custom software	0.01 m	1 Hz

The magnetic and radiometric, altitude and navigation data were monitored on the operator's displays during flight while they were recorded to the PC hard disk drive. Spectrometry data were also recorded to internal hard drive of the spectrometer. The data files were transferred to the field workstation via USB flash drive. The raw data files were backed up onto USB flash drive in the field.

2.3 Airborne Survey Logistics Summary

Traverse (survey) line spacing:	200 metres
Traverse line direction:	90° East-West
Nominal aircraft ground speed:	50 - 150 km/h
Average sensor terrain clearance Mag:	47 metres
Average sensor terrain clearance Rad:	80 metres

Sampling rates: 0.2 seconds - magnetometer
1.0 second - spectrometer, GPS, altimeter

3. DATA PROCESSING AND PRESENTATION

All data were processed by Frode Ofstad and Vikas Baranwal at NGU. The ASCII data files were loaded into separate Oasis Montaj databases (Geosoft 2010). The datasets were processed consequently according to processing flow charts shown in Appendix A1 and A2.

3.1 Total Field Magnetic Data

At the first stage the magnetic data were visually inspected and spikes were removed manually. A non-linear filter was applied to eliminate short-period spikes. Then the data from basemag station were imported into the magnetic database. Diurnal variation channel was also inspected for spikes and spikes were removed manually. Typically, several corrections have to be applied to magnetic data before gridding, as described in the detailed description below.

Diurnal Corrections

The temporal fluctuations in the magnetic field of the earth affect the total magnetic field readings recorded during the airborne survey. This is commonly referred to as the magnetic diurnal variation. These fluctuations can be effectively removed from the airborne magnetic dataset by using a stationary reference magnetometer that records the magnetic field of the earth simultaneously with the airborne sensor. Magnetic diurnals were within the standard NGU specifications during the entire survey (Rønning 2013).

Diurnal variations were measured with a ENVI-Mag base magnetometer. The CPU clock of the base magnetometer was adjusted to UTC time to be synchronized to the recorded airborne magnetic data. The base magnetometer data is merged with the navigation database and the diurnal correction is applied according to equation (1).

$$\mathbf{B}_{Tc} = \mathbf{B}_T + \left(\overline{B}_B - \mathbf{B}_B\right) \quad (1)$$

Where:

$\mathbf{B}_{Tc}$ = Corrected airborne total field readings

$\mathbf{B}_T$ = Airborne total field readings

$\overline{B}_B$ = Average datum base level

$\mathbf{B}_B$ = Base station readings

The average datum base level ($\overline{B}_B$) was calculated to 50346 nT for this survey.

Corrections for Lag and heading

Neither a lag nor cloverleaf tests were performed before the survey. According to previous reports the lag between logged magnetic data and the corresponding navigational data was 1-2 fiducials. Translated to a distance it would be no more than 10 m - the value comparable with the precision of GPS. A heading error for a towed system is usually either very small or non-existent. So no lag and heading corrections were applied.

Magnetic data processing, gridding and presentation

The total field magnetic anomaly data ($\mathbf{B}_{TA}$) were calculated from the diurnal corrected data ($\mathbf{B}_{Tc}$) after subtracting the IGRF for the surveyed area calculated for the data period (eq.2)

$$\mathbf{B}_{TA} = \mathbf{B}_{Tc} - IGRF \tag{2}$$

The total field anomaly data were split in lines and then were gridded using a minimum curvature method with a grid cell size of 50 meters. This cell size is equal to one quarter of the 200m average line spacing. In order to remove small line-to-line levelling errors that were detected on the gridded magnetic anomaly data, the Geosoft Microlevelling technique was applied on the flight line based magnetic database. Then, the microlevelled channel was gridded using again a minimum curvature method with 50 m grid cell size.

The processing steps of magnetic data presented so far, were performed on point basis. The following steps are performed on grid basis. The Horizontal and Vertical Gradient along with the Tilt Derivative of the total magnetic anomaly were calculated from the microlevelled total magnetic anomaly grid. The magnitude of the horizontal gradient was calculated according to equation (3)

$$HG = \sqrt{\left(\frac{\partial B_{TA}}{\partial x}\right)^2 + \left(\frac{\partial B_{TA}}{\partial y}\right)^2} \tag{3}$$

where $\mathbf{B}_{TA}$ is the microlevelled field. The vertical gradient (VG) was calculated by applying a vertical derivative convolution filter to the microlevelled $\mathbf{B}_{TA}$ field. The Tilt Derivative (TD) was calculated according to the equation (4)

$$\text{TD} = \text{atan}(\text{VG}/\text{HG}) \tag{4}$$

Magnetic data gridding and presentation

After the micro levelling technique was applied to the magnetic data to remove small line-to-line levelling errors, a 5x5 convolution filter was passed over the final grid to smooth the grid image.

The Vertical Gradient, Horizontal Gradient and the Tilt Derivative of the total magnetic field were calculated from the resulting total magnetic field grid. These signals transform the shape of the magnetic anomaly from any magnetic inclination to positive body-centred anomaly and it's widely utilized for mapping of structures. A list of the produced maps is shown in Table 3.

3.2 Radiometric data

Airborne gamma-ray spectrometry measures the abundance of Potassium (K), Thorium (eTh), and Uranium (eU) in rocks and weathered materials by detecting gamma-rays emitted due to the natural radioelement decay of these elements. The data analysis method is based on the IAEA recommended method for U, Th and K (International Atomic Energy Agency, 1991). A short description of the individual processing steps of that methodology as adopted by NGU is given bellow.

Energy windows

The Gamma-ray spectra were initially reduced into standard energy windows corresponding to the individual radio-nuclides K, U and Th. Figure 3 shows an example of a Gamma-ray spectrum and the corresponding energy windows.

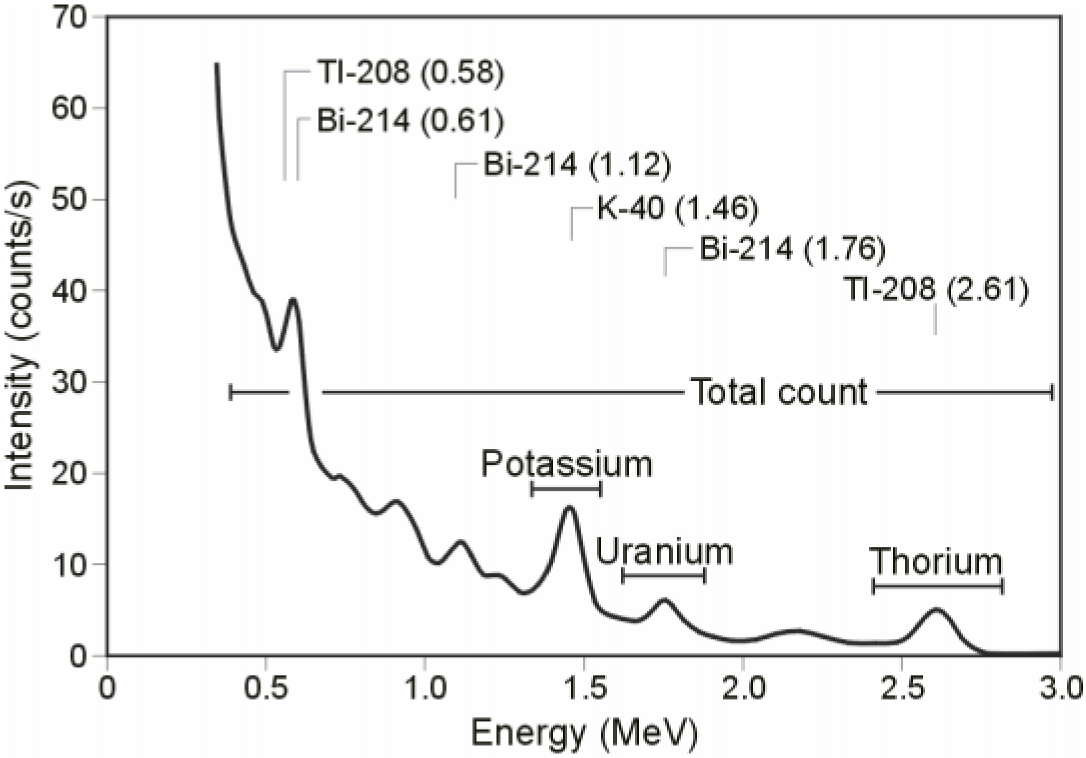

Figure 3: Gamma-ray spectrum with K, Th, U and Total count windows.

The RSX-5 is a 1024 channel system with a four downward looking and one upward looking detector, with a total crystal volume of 16 liters downward and 4 liters upward for cosmic corrections. The Gamma-ray spectrum of 0 to over 3000 keV is divided into 1024 channels, where each channel has 3.0 keV range. Table 2 shows the channels and energies that were used for the reduction of the spectrum.

Table 2: Specified channel windows for the 1024 RSX-5 systems used in this survey

Gamma-ray spectrum	Cosmic	Total count	Potassium	Uranium	Thorium
Down	1022	137-937	457-523	553-620	803-937
Up	1022			553-620	
Energy, keV	>3000	407-2807	1367-1568	1658-1856	2408-2807
Peak, keV			1460	1765	2614
Peak channel			486	586	872

Live Time correction

The data were corrected for live time. “Live time” is an expression of the relative period of time the instrument was able to register new pulses per sample interval. On the other hand “dead time” is an expression of the relative period of time the system was unable to register new pulses per sample interval. The relation between “dead” and “live time” is given by the equation (5)

$$\text{“Live time”} = \text{“Real time”} - \text{“Dead time”} \tag{5}$$

where the “real time” or “acquisition time” is the elapsed time over which the spectrum is accumulated.

The live time correction is applied to the total count, Potassium, Uranium, Thorium, upward Uranium and cosmic channels. The formula used to apply the correction is as follows:

$$C_{LT} = C_{RAW} \cdot \frac{1000000}{Live\ Time} \tag{6}$$

where C_{LT} is the live time corrected channel in counts per second, C_{RAW} is the raw channel data in counts per second and Live Time is in microseconds.

Cosmic and aircraft correction

Background radiation resulting from cosmic rays and aircraft contamination was removed from the Total Count, Potassium, Uranium, Thorium and Upward Uranium channels using the following formula:

$$C_{CA} = C_{LT} - (a_c + b_c \cdot C_{Cos}) \tag{7}$$

where C_{CA} is the cosmic and aircraft corrected channel, C_{LT} is the live time corrected channel a_c is the aircraft background for this channel, b_c is the cosmic stripping coefficient for this channel and C_{Cos} is the low pass filtered cosmic channel.

Radon correction

The upward detector method, as discussed in IAEA (1991), was applied to remove the effects of the atmospheric radon in the air below and around the helicopter. Usages of over-water measurements where there is no contribution from the ground, enabled the calculation of the coefficients a_c and b_c of the linear equations that relate the cosmic corrected counts per second of Uranium channel with total count, Potassium, Thorium and Uranium upward channels over water. Data over-land was used in conjunction with data over-water to calculate the a_1 and a_2 coefficients used in equation (8) for the determination of the Radon component in the downward uranium window:

$$Radon_U = \frac{Uup_{CA} - a_1 \cdot U_{CA} - a_2 \cdot Th_{CA} + a_2 \cdot b_{Th} - b_U}{a_U - a_1 - a_2 \cdot a_{Th}} \tag{8}$$

where $Radon_U$ is the radon component in the downward uranium window, Uup_{CA} is the filtered upward uranium, U_{CA} is the filtered Uranium, Th_{CA} is the filtered Thorium, a_1, a_2, a_U and a_{Th} are proportional factors and b_U an b_{Th} are constants determined experimentally.

The effects of Radon in the downward Uranium are removed by simply subtracting $Radon_U$ from U_{CA}. The effects of radon in the other channels are removed using the following formula:

$$C_{RC} = C_{CA} - (a_C \cdot Radon_U + b_C) \tag{9}$$

where C_{RC} is the Radon corrected channel, C_{CA} is the cosmic and aircraft corrected channel, $Radon_U$ is the Radon component in the downward uranium window, a_c is the proportionality factor and b_c is the constant determined experimentally for this channel from over-water data.

Compton Stripping

Potassium-, Uranium- and Thorium- Radon corrected channels are subjected to spectral overlap correction. Compton scattered gamma rays in the radio-nuclides energy windows were corrected by window stripping using Compton stripping coefficients determined from measurements on calibrations pads at the Geological Survey of Norway in Trondheim (for values see Appendix A2).

The stripping corrections are given by the following formulas:

$$A_1 = 1 - (g \cdot \gamma) - (\mathrm{a} \cdot \alpha) + (\mathrm{a} \cdot g \cdot \beta) - (b \cdot \beta) + (b \cdot \alpha \cdot \gamma) \qquad (10)$$

$$U_{ST} = \frac{Th_{RC} \cdot ((g \cdot \beta) - \alpha) + U_{RC} \cdot (1 - b \cdot \beta) + K_{RC} \cdot ((b \cdot \alpha) - g)}{A_1} \qquad (11)$$

$$Th_{ST} = \frac{Th_{RC} \cdot (1 - (g \cdot \gamma)) + U_{RC} \cdot (b \cdot \gamma - \mathrm{a}) + K_{RC} \cdot ((\mathrm{a} \cdot g) - b)}{A_1} \qquad (12)$$

$$K_{ST} = \frac{Th_{RC} \cdot ((\alpha \cdot \gamma) - \beta) + U_{RC} \cdot ((\mathrm{a} \cdot \beta) - \gamma) + K_{RC} \cdot (1 - (\mathrm{a} \cdot \alpha))}{A_1} \qquad (13)$$

where U_{RC}, Th_{RC}, K_{RC} are the radon corrected Uranium, Thorium and Potassium, a, b, g, α, β, γ are Compton stripping coefficients.

Reduction to Standard Temperature and Pressure

The radar altimeter data were converted to effective height (H_{STP}) using the acquired temperature and pressure data, according to the expression:

$$H_{STP} = H \cdot \frac{273.15}{T + 273.15} \cdot \frac{P}{1013.25} \qquad (14)$$

where H is the smoothed observed radar altitude in meters, T is the measured air temperature in degrees Celsius and P is the measured barometric pressure in millibars.

Height correction

Variations caused by changes in the aircraft altitude relative to the ground corrected to a nominal height of 60 m. Data recorded at the height above 150 m were considered as non-reliable and removed from processing. Total count, Uranium, Thorium and Potassium stripped channels were subjected to height correction according to the equation:

$$C_{60m} = C_{ST} \cdot e^{C_{ht} \cdot (60 - H_{STP})} \qquad (15)$$

where C_{ST} is the stripped corrected channel, C_{ht} is the height attenuation factor for that channel and H_{STP} is the effective height.

Conversion to ground concentrations

Finally, corrected count rates were converted to effective ground element concentrations using calibration values derived from calibration pads at the Geological Survey of Norway in Trondheim (for values see Appendix A2). The corrected data provide an estimate of the apparent surface concentrations of Potassium, Uranium and Thorium (K, eU and eTh).

Potassium concentration is expressed as a percentage, equivalent Uranium and Thorium as parts per million. Uranium and Thorium are described as "equivalent" since their presence is inferred from gamma-ray radiation from daughter elements (^{214}Bi for Uranium, ^{208}TI for Thorium). The concentration of the elements is calculated according to the following expressions:

$$C_{CONC} = C_{60m} / C_{SENS\_60m} \quad (16)$$

where C_{60m} is the height corrected channel, C_{SENS_60m} is experimentally determined sensitivity reduced to the nominal height (60m).

Spectrometry data gridding and presentation

Gamma-rays from Potassium, Thorium and Uranium emanate from the uppermost 30 to 40 centimeters of soil and rock in the crust (Minty, 1997). Variations in the concentrations of these radio-elements largely related to changes in the mineralogy and geochemistry of the Earth's surface.

The calculated ground concentrations of the three main natural radio-elements Potassium, Thorium and Uranium, along with total gamma ray flux (Total Count) were microlevelled to remove small line-to-line levelling errors, as in the case of the magnetic data, and then gridded using a minimum curvature method with a grid cell size of 50 meters. This cell size is equal to one quarter of the 200m average line spacing.

The quality of the radiometric data was within standard NGU specifications (Rønning 2013).
A list of the available maps is shown in Table 3. A list of the parameters used in the processing is given in Appendix A2. For further reading regarding standard processing of airborne radiometric data, we recommend the publication from Minty et al. (1997).

4. PRODUCTS

Table 3: Maps in scale 1:50.000 available from NGU on request.

Map #	Name	Figure No
2012.075-01	Total magnetic field	4
2012.075-02	Magnetic Vertical Derivative	5
2012.075-03	Magnetic Horizontal Derivative	6
2012.075-04	Magnetic Tilt Derivative	7
2012.075-05	Uranium ground concentration	8
2012.075-06	Thorium ground concentration	9
2012.075-07	Potassium ground concentration	10
2012.075-08	Radiometric Ternary Map	11

Downscaled images of the maps are shown on figures 4 to 11.

Processed digital data from the survey are presented as:

1. Geosoft XYZ files: Nissedal_Mag.xyz, Nissedal_Rad.xyz.

2. Colored maps (jpg) at the scale 1:50.000 available from NGU on request.

3. Geo-referenced tiff files (Geo-tiff).

5. REFERENCES

IAEA 1991: Airborne Gamma-Ray Spectrometry Surveying, Technical Report No 323, Vienna, Austria, 97 pp.

IAEA 2003: Guidelines for radioelement mapping using gamma ray spectrometry data. IAEA-TECDOC-1363, Vienna, Austria, 173 pp.

Minty, B.R.S. 1997: The fundamentals of airborne gamma-ray spectrometry. AGSO Journal of Australian Geology and Geophysics, 17 (2): 39-50.

Minty, B.R.S., Luyendyk, A.P.J. and Brodie, R.C. 1997: Calibration and data processing for gamma-ray spectrometry. AGSO Journal of Australian Geology and Geophysics, 17(2): 51-62.

Naudy, H. and Dreyer, H. 1968: Non-linear filtering applied to aeromagnetic profiles. Geophysical Prospecting. 16(2). 171-178.

Rønning, J.S. 2013: NGUs helikoptermålinger. Plan for sikring og kontroll av datakvalitet. NGU Intern rapport 2013.001, (38 sider).

Geosoft 2010: Montaj MAGMAP Filtering, 2D-Frequency Domain Processing of Potential Field Data, Extension for Oasis Montaj v 7.1, Geosoft Corporation

Appendix A1: Flow chart of magnetic processing

Meaning of parameters is described in the referenced literature.

Processing flow:

- Quality control.
- Visual inspection of airborne data and manual spike removal
- Import basemag data to Geosoft database
- Inspection of basemag data and removal of spikes
- Correction of data for diurnal variation
- Splitting flight data by lines
- Gridding
- Micro-leveling
- 5x5 Convolution filter

Appendix A2: Description of radiometry processing

Underlined processing stages are applied to the K, U, Th and TC windows.
Meaning of parameters is described in the referenced literature.

Processing flow:

- Quality control
- Airborne and cosmic correction (IAEA, 2003)

Used parameters: (determined by high altitude calibration flights at Frosta in May 2013)

Aircraft background counts:

K window	9
U window	3
Th window	0
Uup window	0
Total counts	59

Cosmic background counts (normalized to unit counts in the cosmic window):

K window	0.0610
U window	0.0454
Uup window	0.0237
Th window	0.0626
Total counts	1.0536

- Radon correction using upward detector method (IAEA, 2003)

Used parameters (determined from survey data over water and land):

a_u:	0.456	$b_{u:}$	1.0064
a_{Th}:	0.1266	b_{Th}:	1.0531
a_K:	0.1.0878	b_K:	1.7199
$a_{Tc:}$	15.44	$b_{Tc:}$	4.9111
a1:	0.081	a_2:	0.008

- Stripping correction (IAEA, 2003)

Used parameters (determined from measurements on calibrations pads at the NGU in May 2013):

a	0.04824
b	0
g	0
alpha	0.30867
beta	0.48072
gamma	0.79531

- Height correction to a height of 60 m

Used parameters (determined by high altitude calibration flights at Frosta in Jan 2014):
Attenuation factors in 1/m:

K:	-0.0107
U:	-0.0067
Th:	-0.0062
TC:	-0.0076

- Converting counts at 60 m heights to element concentration on the ground

Used parameters (determined from measurements on calibrations pads at the NGU in May 2013):
Sensitivity (elements concentrations per count):

K:	0.007615734	%/counts
U:	0.086685504	ppm/counts
Th:	0.157230960	ppm/counts

- Microlevelling using Geosoft menu and smoothening by a convolution filtering

Used parameters for microlevelling:

De-corrugation cutoff wavelength:	2000 m
Cell size for gridding:	50 m
Naudy (1968) Filter length:	800 m

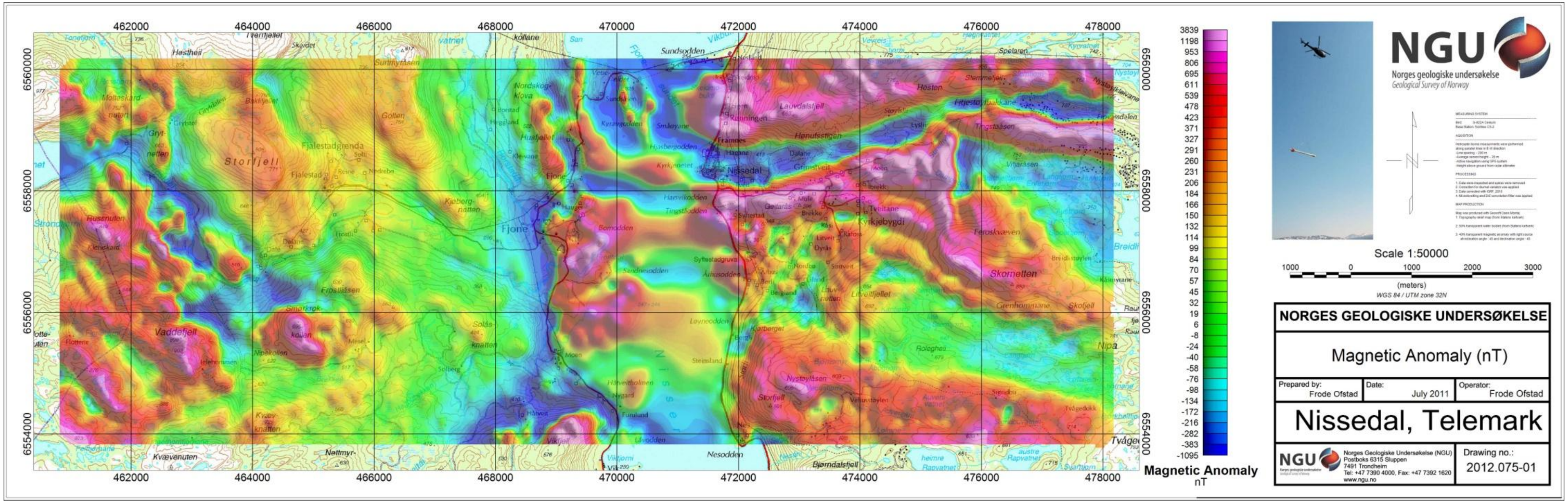

Figure 4: Magnetic Total Field Anomaly

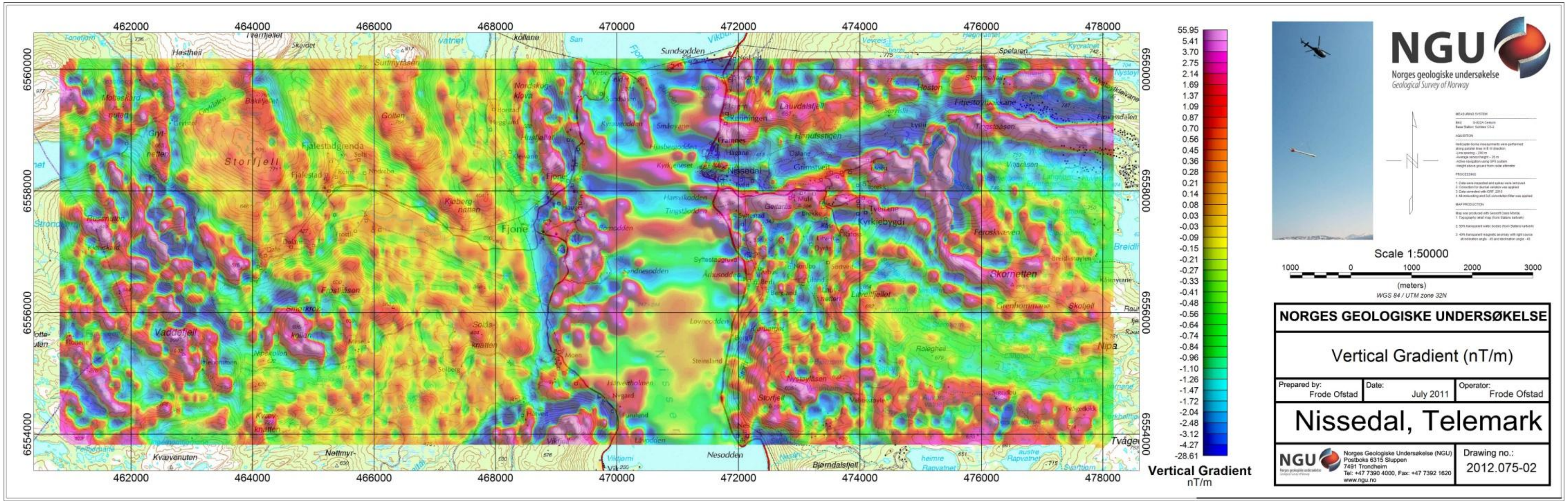

Figure 5: Magnetic Vertical Gradient

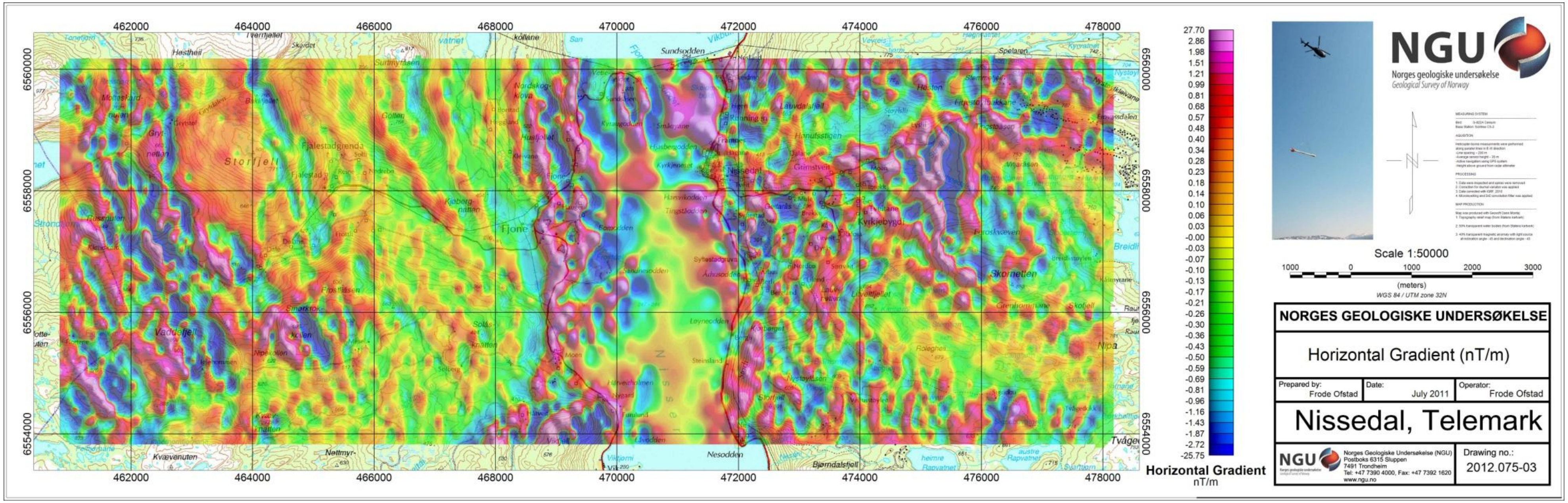

Figure 6: Magnetic Horizontal Gradient

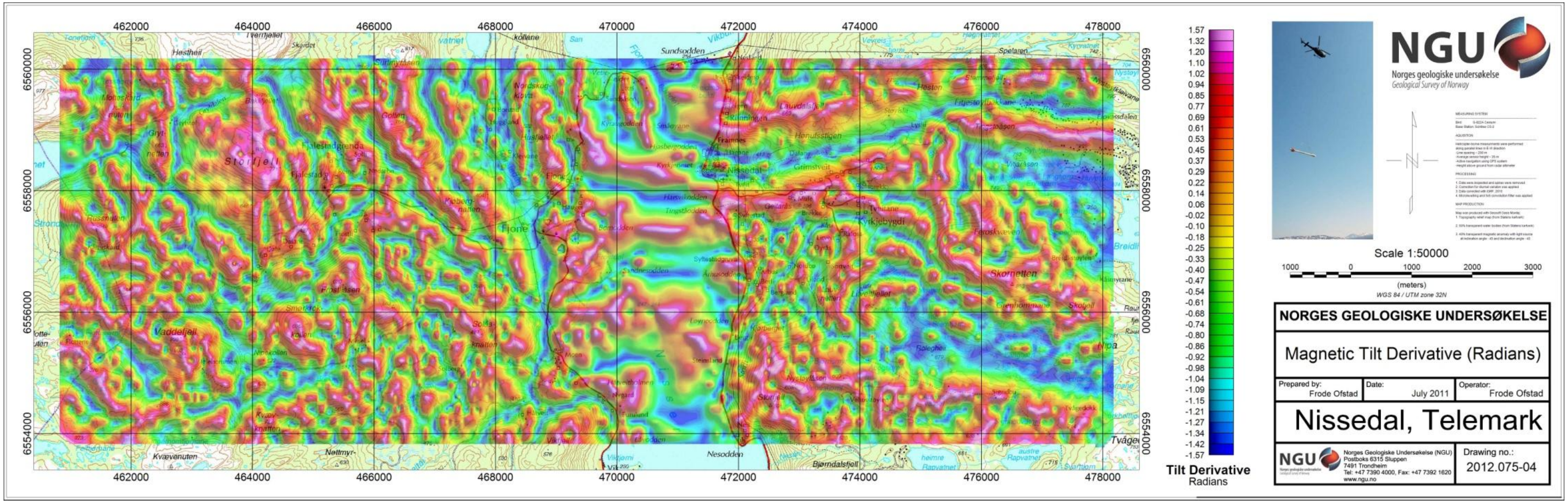

Figure 7: Magnetic Tilt Derivative

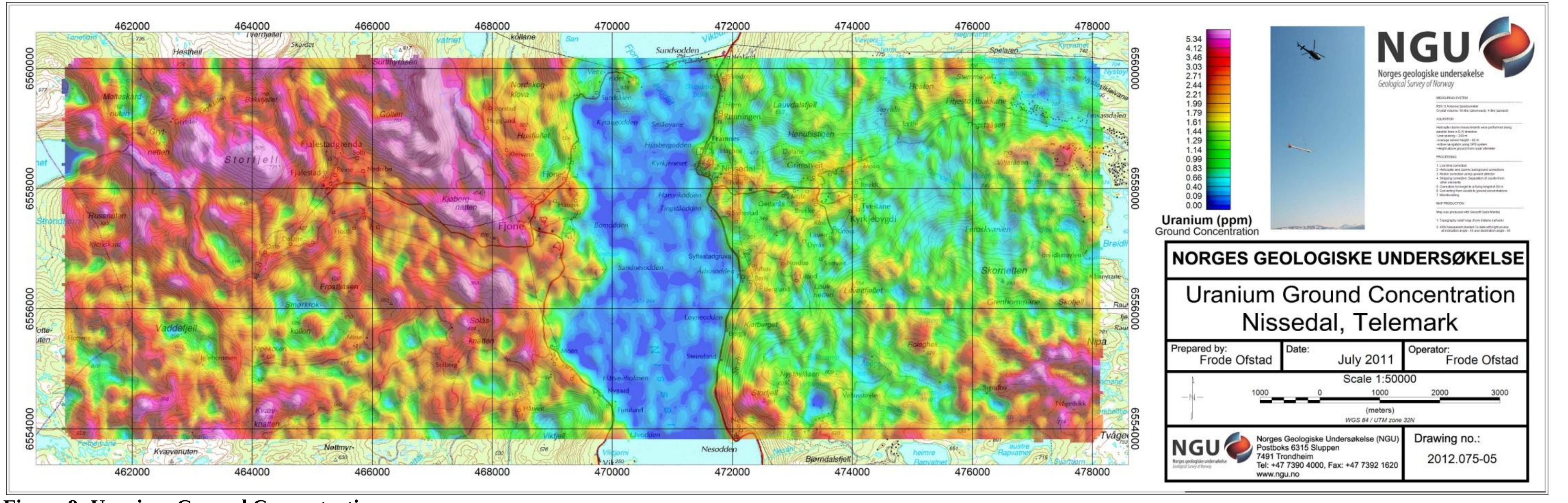

Figure 8: Uranium Ground Concentration

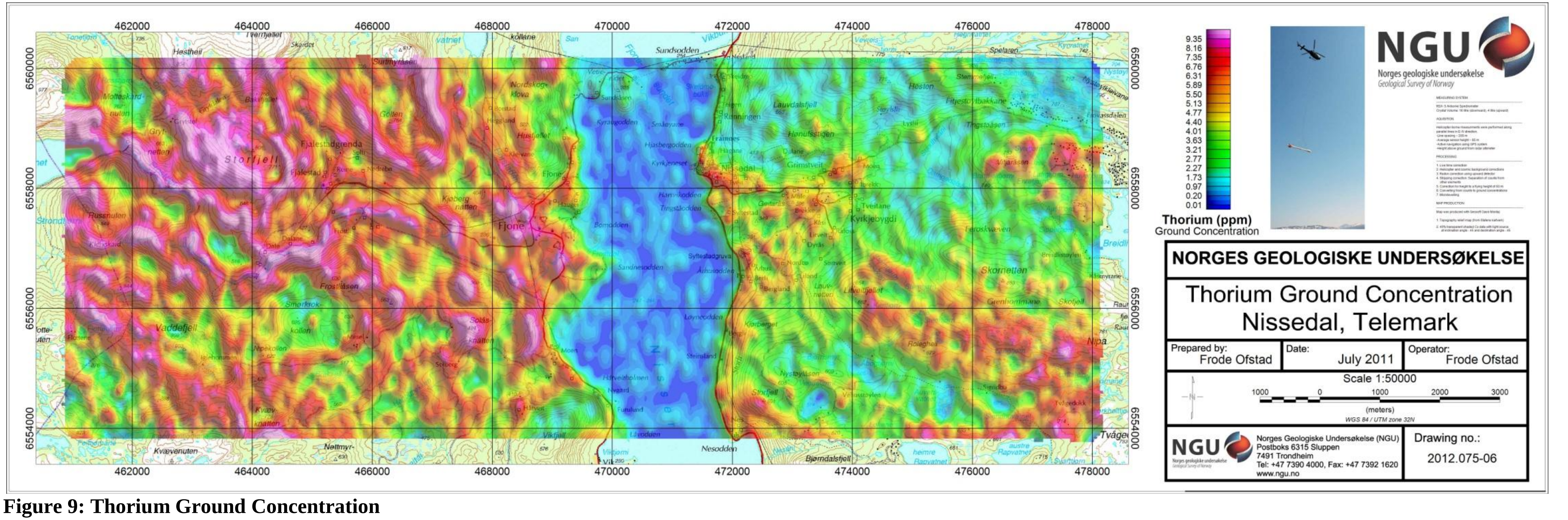

Figure 9: Thorium Ground Concentration

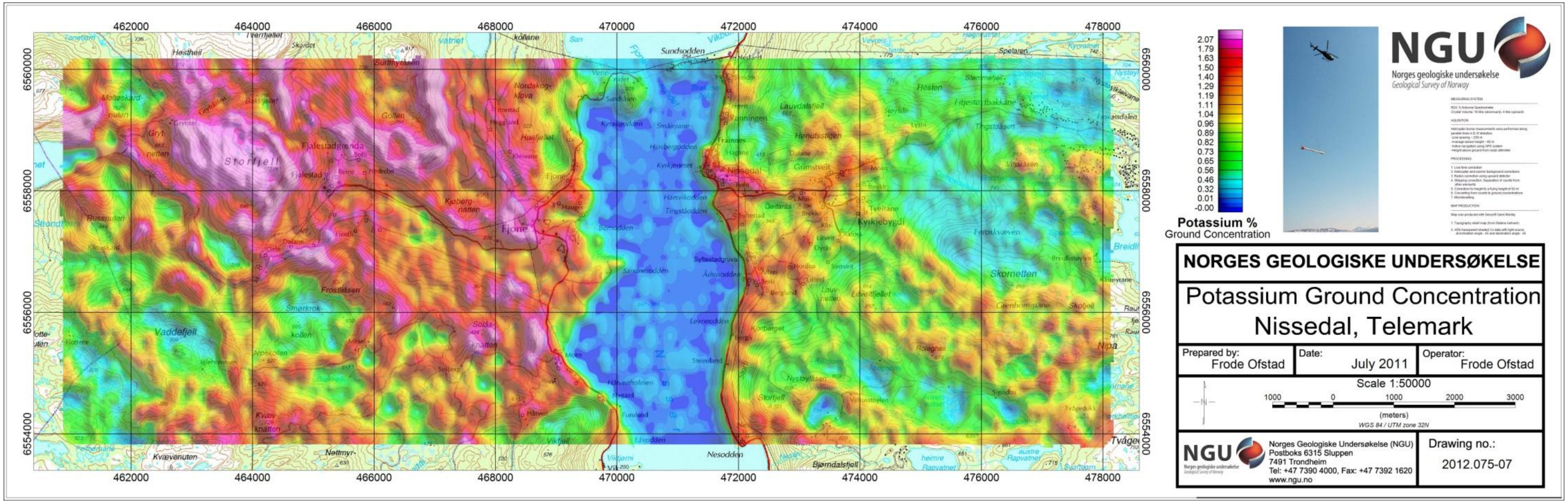

Figure 10: Potassium Ground Concentration

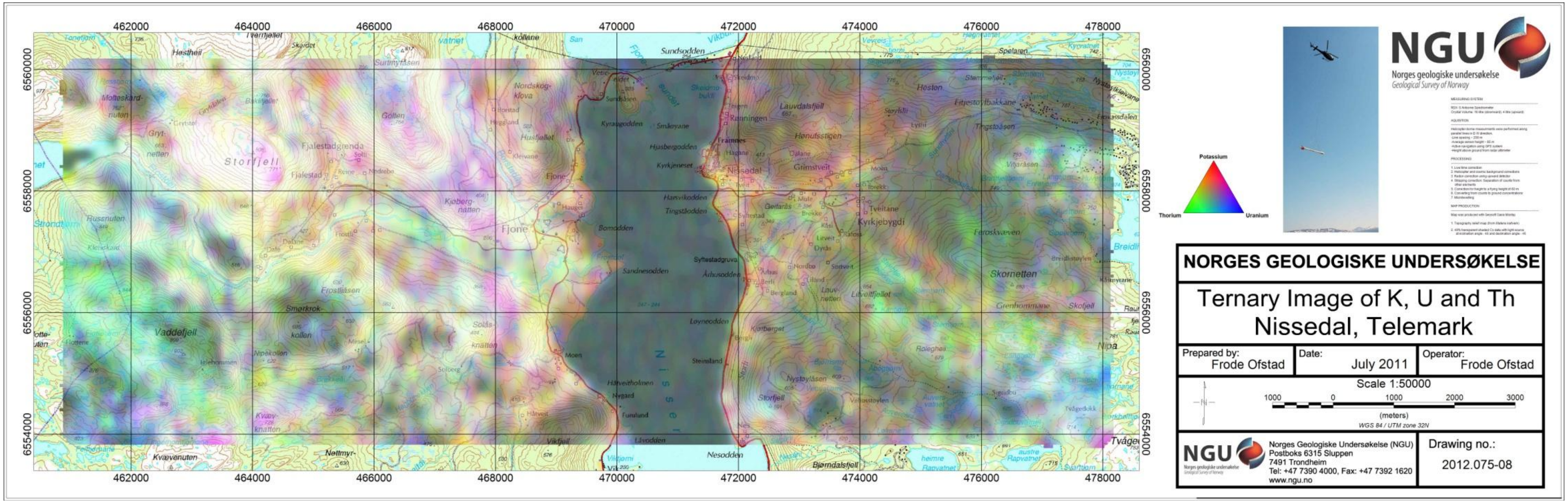

Figure 11: Ternary Image of Radiation Concentrations

NGU
Norges geologiske undersøkelse
Geological Survey of Norway

Norges geologiske undersøkelse
Postboks 6315, Sluppen
7491 Trondheim, Norge

Geological Survey of Norway
PO Box 6315, Sluppen
7491 Trondheim, Norway

Besøksadresse
Leiv Eirikssons vei 39, 7040 Trondheim

Visitor address
Leiv Eirikssons vei 39, 7040 Trondheim

Telefon 73 90 40 00
Telefax 73 92 16 20
E-post ngu@ngu.no
Nettside www.ngu.no

Tel (+ 47) 73 90 40 00
Fax (+ 47) 73 92 16 20
E-mail ngu@ngu.no
Web www.ngu.no/en-gb/